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Dietary fibre and health in children and adolescents

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The role of dietary fibre in promoting sustained health has been studied for several decades and in adults there is good evidence that diets rich in high-fibre foods reduce the risk of chronic diseases, including CVD and cancer. Research in this area, however, has been hampered by uncertainties about the definition of dietary fibre which has resulted in many studies measuring fibre in different ways. There is also a wide range of properties and actions of different fibres in the human body, depending on their solubility, viscosity and fermentability by the colonic microbiota. This review considers the epidemiological evidence for dietary fibre and health in children and the current dietary recommendations and measured intakes in several countries using national surveys. In children and adolescents, there is a particular lack of relevant research on which to formulate appropriate dietary fibre recommendations and these are often based on extrapolation from adult data. However, children are not little adults and have differing physiology and nutritional needs as they grow. The dietary recommendations in different countries are based on varying premises and daily amounts. Intakes vary from country to country and on the whole do not meet recommendations. Much more research is needed in children to fully understand the impact of dietary fibre on growth and health in the young to allow more appropriate recommendations to be made.

Dietary fibre: Children: Dietary recommendations: Dietary fibre intake

Dietary fibre research in childhood has been fraught with problems that have restricted the number and type of studies carried out and therefore the evidence on which to base dietary guidelines and advice. The definition of dietary fibre has been a major controversy for decades with different approaches used in some countries which make comparison of studies very difficult. It is also difficult to study diet in children and adolescents for ethical and practical reasons. This means that observational studies are few and intervention studies very limited in number.

Dietary recommendations for dietary fibre have also been based mainly on extrapolation of adult data or related to energy intakes. There was an initial fear that a high-fibre diet may cause inadequate energy intake and inhibition of micronutrient absorption. This may still be relevant in those with very poor diets with foods of low digestibility. However, in a world with increasing childhood obesity, these factors are less important and finding ways to reduce the energy density of the diet and preventing chronic diseases becomes more important. This has led to re-evaluation of dietary fibre recommendations for children but much is still based on extrapolation rather than solid evidence. In parallel, continued debate about the definition of dietary fibre[1] and growing awareness of the importance of the gut microbiome in a range of acute and chronic conditions[2–7] has added to the impetus for understanding the role of dietary fibre in childhood in establishing sustained health and prevention of chronic disease. In this review, the current recommendations for childhood will be discussed alongside evidence for the effects of dietary fibre.

What is fibre?

Dietary fibre, in principle, is non-digestible carbohydrate that reaches the colon, is available for fermentation by

Abbreviations: MetS, metabolic syndrome.
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colonic bacteria, may impact on gut physiology, nutrient absorption and metabolism and may, if not well fermented, increase stool output. However, which carbohydrates should be considered as dietary fibre? Previously there was division between countries using the AOAC-based definition and those, including the UK, using NSP[8]. The AOAC method includes NSP and some but not all resistant starch. This meant that estimates of dietary fibre using the AOAC definition in some foods were sometimes considerably higher than when dietary fibre was estimated as NSP. In addition, there are lower molecular weight non-digestible carbohydrates such as fructo-oligosaccharides and pyrodextrins which would not be included in either definition, despite reaching the human colon intact and having many of the actions of fermentable dietary fibres. More recently there have been attempts to harmonise the definition and in 2010 dietary fibre, according to the Codex Alimentarius[9,10], was defined as ‘carbohydrate polymers with ten or more monomeric units, which are not hydrolysed by the endogenous enzymes in the small intestine of humans’. The decision to include carbohydrates from three to nine monomeric units was left to national authorities and this caused further debate[1]. Many organisations have now adopted this definition[11–15], including those in the UK[16]. The associated increase in the recommended intake of fibre may cause confusion and as research studies are still using older definitions and national intakes in the UK have been based on NSP clarity is needed. Another issue is that the physiological effects of fibre differ from one non-digestible carbohydrate to another and 1 g fibre as a concept does not really infer particular levels of impact on gut physiology or health. It all depends on the type of fibre eaten as soluble and insoluble fibres have different effects in the upper and lower intestines[17] and some of the actions of fibre may be mediated by SCFA production in the colon[18,19] and this also differs between carbohydrate sources. This is one reason for the difficulties in establishing the health effects of dietary fibre in epidemiological studies.

The beneficial role of dietary fibre is reasonably well documented for adults. A pooled analysis of ten prospective cohort studies indicated that every 10 g/d increase of dietary fibre was associated with decreased risk of coronary events and coronary death by 14 and 27 %, respectively[20]. A recent meta-analysis of twenty cohort studies also confirmed an association between higher dietary fibre consumption and lower risk of CVD[21]. The role of dietary fibre in reducing risk of colon cancer has been difficult to establish but the systematic review by the World Cancer Research Fund and American Institute of Cancer Research (www.wcrf.org/int/research-we-fund/continuous-update-project-cup/second-expert-report) concluded there was probable evidence for a reduction in risk of colorectal cancer by consumption of fibre-rich foods and the more recent European Prospective Investigation into Cancer and Nutrition study has reported stronger evidence for the protective role of high dietary fibre intakes[22]. The American Dietetic Association concluded that a high-fibre intake may be associated with desirable outcomes regarding bowel function, diabetes control and weight management[23].

In 2001, the Institute of Medicine in the USA recommended intakes of 30 g dietary fibre daily for adults based on protective effects against CVD. Other organisations followed suit recommending an intake of at least 25 g dietary fibre daily for the general population[14,24,25].

Dietary fibre recommendations for children and adolescents

Recommendations for dietary fibre in children remain based on extrapolation and guesswork from adult studies and vary across countries, as most studies of dietary fibre have focused on adults. While some reviews have considered the evidence of dietary fibre in childhood and adolescence[26–31], most are based on limited studies. Kranz *et al.*[28] failed to identify many studies examining the effects of fibre intake on childhood constipation, obesity and diabetes. The Scientific Advisory Committee on Nutrition draft report[16] retrieved only three prospective studies. We have collected information on dietary recommendations from several countries (Table 1). In addition to six mainstream English-speaking countries (Australia, Canada, Ireland, New Zealand, UK and USA) from which recommendations[8,13,16,32,33] and surveys[34–42] were retrieved, five additional recommendations[12,14,15,43,44] and five nutrition surveys[45–49] were obtained. Five papers[23,31,45,50,51] where recommendation and/or intakes were discussed were also included.

Dietary fibre intake recommendations for children and adolescents ranged from 10 to 40 g/d, depending on age, gender and energy intake (Table 1). The current recommendations in the UK[8] and in German-speaking countries described in the D-A-CH-Referenzwerte[43] gave no recommended amount for children, stating rather that lower intakes than adults should be applied. The UK recommendations have been updated in the draft report by Scientific Advisory Committee on Nutrition[16], dietary fibre (not NSP) recommendations for children are 5 g/d for 2–5 years, 20 g/d for 5–11 years, 25 g/d for 11–16 years and 30 g/d for 16–18 years. Many fibre recommendations were also expressed as a function of energy intake, from 2 to 3·4 g/MJ per d (8·2–14 g/kcal per d)[12,14,15,32]. The highest energy-adjusted fibre intake recommendation (3·4 g/MJ per d) was proposed by the US Institute of Medicine, based on the protective effects against CHD observed in adults[32]. Others based their intake on age +5 g/d[31] recommended by the American Health Foundation[30]. Australia and New Zealand set their adequate intake as the median dietary fibre intake from national dietary data plus an allowance ranging from 2 to 4 g/d for the resistant starch which may not be included in these data[13].

Although very high dietary fibre intake may have potential adverse effects such as decreased mineral absorption and development failure in high risk children[27,30], no upper limits for dietary fibre were set in these recommendations. It is believed that in highly industrialised

Table 1. Dietary fibre intake recommendations for children and adolescents in selected countries and regions

Country	Body issuing the recommendation	Age (year)	Recommended fibre intake (per d)	Rationale recommendation based on
		1–3	14 g	
Australia and New Zealand	National Health and Medical Research Council	4–8	18 g	Median fibre intake from national dietary surveys
		9–13	24 g (M), 20 g (F)	
		14–18	28 g (M), 22 g (F)	
		⩾ 1	3·4 g/MJ	
		1–3	19 g	
Canada and USA	Institute of Medicine	4–8	25 g	Adult data on reduced risk for CHD.
		9–13	31 g (M), 26 g (F)	Absolute amount calculated from median energy intake
		14–18	38 g (M), 26 g (F)	
USA	American Health Foundation	3–20	Age + 5 g	Practical and safety considerations
France	French Food Safety Agency	1–12	Age + 5 g	
		13–19	30 g	
Ireland	Food Safety Authority of Ireland	5–18	Age + 5 g	
		1–3	15 g	
		4–8	25 g (M), 20 g (F)	IoM's recommendation.
Netherlands	Health Council of Netherlands	9–13	30 g (M), 25 g (F)	Absolute amount calculated from median energy intake
		14–18	40 g (M), 30 g (F)	
		1–18	2 g/MJ	
		1–3	10 g	
Europe	European Food Safety Authority	4–6	14 g	Normal laxation.
		7–10	16 g	Absolute amount calculated from median energy intake
		11–14	19 g	
		15–17	21 g	
Nordic countries	Nordic Council of Minister	2–18	2–3 g/MJ	Adult data on reduced risk for CRC, CVD, T2DM

M, male; F, female; CRC, colorectal cancer; T2DM, type 2 diabetes mellitus.

countries increasing fibre intake is unlikely to compromise growth and development[14,32].

Current intakes of children and adolescents

National nutrition surveys were obtained covering the main countries of Europe, North America and Oceania most of which are highly industrialised. Owing to the adoption of different dietary collection methods, different years of data collection, different age groups, and definitions of dietary fibre, direct comparison between surveys is limited. Although fibre intake varied across countries, genders and age groups, it was associated with energy intake (Table 2). In Europe, the highest intakes were observed in Poland (and Slovenia) followed by Nordic countries (e.g. Denmark, Netherlands and Norway). However, Finland reported lower fibre intake. Intakes in Greece and Italy were also relatively high. Australia and New Zealand had higher fibre intakes than most other countries, including USA and Canada (based on median).

Based on these data children in most countries failed to achieve the recommended intakes (Table 2). Low-fibre intake during early life may impose long-term adverse effects, including obesity in later life[26]. However, the 'fibre gap' may result from high-fibre recommendations not based on evidence in children[12,32].

Dietary fibre and health in children

A systematic review of studies investigating the association between dietary fibre intake and health outcomes of children and adolescents was carried out using procedures recommended by Cochrane and PRISMA[52,53].

Search strategy

Prospective cohort studies and cross-sectional studies in children aged from 1 to 18 years from 1990 until 20 May 2014 were included. MEDLINE and EMBASE via Ovid™ were used. For exposure both free-text and MeSH terms of dietary fibre and its sub-fractions were used, and they were combined with Boolean operator 'AND' instead of 'OR', to reduce the sensitivity and keep records manageable. Criteria included subject, exposure, study design, language and publish date (Table 3), when selecting entries from the search strategies. Any outcomes were included due to the risk of missing potentially relevant studies, and all outcomes of studies selected were grouped accordingly.

Initially 1565 records were identified in the search. Reading of titles and abstracts narrowed this to 185 papers. Nine cross-sectional studies[54–62] and eight prospective cohort studies[60,63–69] were identified after screening for full-texts. After grouping studies in accordance with outcomes of interest, one cross-sectional study[56]

Table 2. Nutrition surveys of fibre intake in children data from [24,34–49,51]

Country Year	Age (year)	Dietary method	Mean fibre intake boys (g/d)	Mean fibre intake girls (g/d)
Australia 2007	2–3	2 × 24-h recall	16·7	15·5
	4–8		19·2	18·0
	9–13		23·9	20·7
	14–16		27·5	21·5
Austria 2007	7–9	3-d food record	15·0	14·3
2003–2004	10–14	24-h recall	15·1	13·7
	14–>19		15·6	13·8
Belgium 2002–2003	2·5–3	3-d food record	14·6	13·0
	4–6·5		14·6	13·9
1997	13–15	7-d food record	1·8 (g/MJ)	2·0 (g/MJ)
Canada 2004	9–13	24-h recall	16·3 (median)	14·0 (median;
	14–18		18·2 (median)	for 9–18 years)
Denmark 1995	1–3	7-d food record	15·0	14·0
2005–2008	4–5		17·0	16·0
	6–9		18·0	17·0
	10–13		18·0	15·0
	14–17		19·0	15·0
Finland 2008	4	3-d food record	9·6	9·4
	6		11·4	10·3
Germany 2006	6	3-d food record	15·7	15·8
	7–9		17·5	16·8
	10–11		17·9	17·7
	12	Dietary history	25·3	25·0
	13–14		27·7	24·4
	15–17		26·1	23·1
Greece 1997	2–3	3-d food record	10·6	9·8
	4–5		11·9	11·6
	6–7		13·9	12·8
	8–9		14·7	13·1
	10–11		15·6	14·1
	12–14		16·7	15·4
France 2006–2007	4–6	3 × 24-h recall	11·8	11·5
	7–9		13·5	12·2
	10–14		15·2	13·8
	15–18		16·9	12·7
Hungary 2005–2006	11–14	3 × 24-h recall	20·8	20·1
Ireland (NSP) 2005	5–8	7-day record	9·2	8·5
	9–12		10·8	9·2
2008	13–14		12·3	9·7
	15–17		13·7	10·3
Italy	4–6	7-d food record	14·9	15·8
	7–9		18·5	15·2
	10–14		21·6	16·8
	15–18		23·9	17·6
Netherlands	2–3	2-d food record	13·0	12·0
2005–2006	4–6		14·0	13·0
1997–1998	7–9		17·0	15·0
	10–12		19·0	17·0
	13–15		22·0	18·0
	16–18		24·0	19·0
New Zealand 2002	5–6	24-h recall	18·4	14·7
	7–10		19·1	16·8
	11–14		22·0	17·5
	5–14		19·9	16·7
Norway 2000	4	4-d food record	12·0	12·0
	9		16·0	14·0
	13		16·0	14·0
1997	16–19	FFQ	26·0	21·0

Table 2. (*Cont.*)

Country Year	Age (year)	Dietary method	Mean fibre intake boys (g/d)	Mean fibre intake girls (g/d)
Poland 2000	4–6	24-h recall	16·8	14·6
	7–9		19·6	17·4
	10–14		24·6	20·9
	15–18		32·6	23·0
Portugal 2000–2002	7–9	24-h recall	20·2	19·4
	13		25·4	25·2
Slovenia	15–18	FFQ	33·0	27·0
Spain 2002–2003	10–14	2 × 24-h recall	18·5	17·5
	15–18		18·9	16·2
Sweden 2002–2003	4	4-d food record	12·0	11·0
	8–9		14·0	13·0
	11–12		13·0	12·0
Switzerland 2005	6–14	2 × 24-h recall	16·9	16·8
USA 2009–2010	2–5	24-h recall	12·1	11·3
	6–11		13·6	14·5
	12–19		16·7	12·6
UK (NSP) 2008–2012	4–10	4-d food record	11·5	10·7
	11–18		12·8	10·7

investigating dietary fibre intake and folate status and one repeated publication[57] were excluded. Additionally, after performing adapted search commands on other databases and scanning the reference lists from included studies, two further cross-sectional studies[70,71] and five prospective cohort[64,72–75] studies were identified and included. In total, fifteen cross-sectional studies and eleven cohort studies were included in the present review.

Cross-sectional studies

Dietary fibre intake and body weight/composition

Data from the National Health and Nutrition Examination Survey was used to investigate the association between fibre intake and childhood obesity risk, and found a decreased risk in children (2–18 years) for overweight between the medium tertile of energy-adjusted fibre intake and the lowest tertile (OR 0·83, $P = 0·043$) and a further odds reduction between the highest and lowest tertiles of fibre intake (OR 0·79, $P = 0·031$). This was a large nationally representative sample (n 4667) with fibre consumption reported using 24 h recalls validated and screened to include only plausible dietary intake. Models were adjusted for common confounders but not for physical activity[70].

The association between adolescent fibre consumption and visceral fat was studied in a medium-size cohort (n 559) of adolescents (14–18 years). Dietary fibre intake was inversely related to visceral adipose tissue in both genders after adjustment for factors such as fat-free soft tissue, physical activity and energy intake ($\beta = -0·272$, $P = 0·028$ for visceral fat in boys; $\beta = -0·244$, $P = 0·015$ for visceral fat in girls)[61].

In another medium-size Brazilian cohort in adolescents (n 716)[55], dietary fibre intake below the 'age plus 5' recommendation was associated with being overweight (BMI > 85th percentile) after adjustment for gender, type of schooling (public or private) and constipation status (OR = 2·06, $P < 0·001$). However, dietary fibre intake was determined by a single 24 h recall, and the model failed to adjust for physical activity levels.

Dietary fibre intake and constipation

In a study of eighty-four English children (7–10 years) fibre intake was determined by 7-d food records and constipation measured using a parent-completed bowel function diary and judged by the Rome II criteria. There was no difference in fibre intake between the constipated and non-constipated groups. In this small sample, no adjustments for confounding were made[76]. Contrary results were reported in a larger study in Hong Kong in which parents of children aged 3–5 years (n 368) reported fibre consumption and constipation using questionnaires and Rome II criteria. A significantly higher ($P = 0·044$) fibre intake in non-constipated children than constipated counterparts was found but no adjustments for confounding were made[59]. In another medium-size Brazilian cohort (716 adolescents), dietary fibre intake below the 'age plus 5' recommendation was associated with higher odds for constipation (OR 2·84 and 2·95 for males and females, respectively) after adjustment for gender, schooling and BMI > 85th percentile[55]. Dietary fibre intake was determined by a single 24 h recall, constipation was evaluated by self-reported questionnaires and there was no adjustment for physical activity levels. Overall the limited evidence is conflicting and of poor quality due to its observational nature and the limitations of dietary assessment methods.

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Table 3. Search strategy for studies of dietary fibre in children and adolescents

	Search terms	Records
1	exp child/ or (adolescen* or children).tw	1802013
2	dietary fiber/ or prebiotics/ or alginates/ or carrageenan/ or chitin/ or chitosan/ or fructans/ or inulin/ or fungal polysaccharides/ or galactans/ or agar/ or beta-glucans/ or lentinan/ or sizofiran/ or zymosan/ or cellulose/ or cellobiose/ or methylcellulose/ or dextrins/ or cyclodextrin/ or glycosaminoglycans/ or mannans/ or oligosaccharides/ or sepharose/ or xylans/ or lignin/	137675
3	(dietary fiber or dietary fibre or prebiotic* or alginate* or carrageenan* or chitin* or chitosan* or fructan* or inulin* or fungal polysaccharide* or galactan* or agar* or beta-glucan* or lentinan* or sizofiran* or zymosan* or cellulose* or cellobiose* or (methyl-cellulose* or methylcellulose*) or dextrin* or cyclodextrin* or glycosaminoglycan* or mannan* or (oligosaccharide* or oligo-saccharide*) or trehalose* or (trisaccharide* or tri-saccharide*) or acarbose* or raffinose* or pectin* or (plant gum or plant gums or gum or gums) or (plant mucilage* or mucilage*) or sepharose* or xylan* or lignin* or (glucomannan* or gluco-mannan* or hemicellulose* or (fructooligosaccharide* or fructo-oligosaccharide*) or (galactooligosaccharide* or galacto-oligosaccharide*) or (mannan-oligosaccharide* or mannan-oligo saccharide* or mannan oligosaccharide*) or (xylooligosaccharide* or xylo-oligosaccharide*) or (oligofructose* or oligo-fructose*) or polydextrose* or polyfructose* or resistant starch* or (resistant polysaccharide* or resistant carbohydrate*) or (resistant oligosaccharide* or resistant oligo-saccharide*) or (nonstarch polysaccharide* or non-starch polysaccharide * or nonstarch carbohydrate* or non-starch carbohydrate*) or (nondigestible polysaccharide* or non-digestible polysaccharide* or nondigestible carbohydrate* or non-digestible carbohydrate*) or (Metamucil* or Citrucel* or fybogel*) or arabinoxylan* or arabinoglactan*).tw	288916
4	1 AND 2 AND 3	1565
Parameters	**Inclusion criteria**	**Exclusion criteria**
Participant	Participants 1–18 years; or adults who were followed up from childhood	n.a
Exposure	Dietary fibre defined (sub-fractions specified or total fibre determined by AOAC, Englyst, Southgate or equivalent method) or food composition table used stated if no definition. Fibre dose given or assessed by weighed/estimated food records, diet recall, food diaries, history, or FFQ, in g/d, g/MJ, g/kcal, ranges or quantiles	Studies where whole grain intake, or fruit and vegetable intake, etc. rather than dietary fibre intake, were reported. Studies of dietary pattern or dietary score, rather than dietary fibre intake and effects of fibre could not be isolated
Study design	Prospective cohort studies or cross-sectional studies published in English	Retrospective cohort studies, case-control studies, case series, single case report

Dietary fibre intake and metabolic syndrome

In a study using the National Health and Nutrition Examination Survey data from 2028 adolescents (12–19 years) there was a 3-fold decrease between the highest and lowest quintiles in energy-adjusted fibre intake (3·2 *v.* 9·3 %, $P < 0·001$) and incidence of metabolic syndrome (MetS) as defined by the Adult Treatment Panel II MetS criteria. Statistical adjustments were made for factors such as family income, cholesterol intake and saturated fat intake[54]. In another US cohort of 106 overweight Latino adolescents (12–15 years), Ventura *et al.*[62] found that soluble fibre intake was significantly higher in adolescents with non-MetS features (defined by age-modified Adult Treatment Panel III MetS criteria) than those with three or more features ($P < 0·05$). However, this was a small homogeneous at-risk cohort (overweight Latino children with a family history of type 2 diabetes), and may not be extrapolated to other populations. The dietary methods in both studies used 24 h recalls with possible recall bias. From the limited evidence of these two cross-sectional studies in US adolescents, high-fibre intake may be associated with a reduction of MetS risk.

Dietary fibre intake and insulin resistance

The association between fibre intake and insulin sensitivity was studied in a Canadian cohort of 415 children (8–10 years)[71]. After adjusting for demographic and lifestyle factors there was no association between fibre intake and insulin sensitivity. In contrast, a smaller Danish cohort study of 233 children (8–10 years) found in a multi-variance adjusted analysis that higher fibre intake was associated with lower insulin resistance just in girls (Homeostasis model assessment Z-score : $\beta = -1{\cdot}18$, $P = 0{\cdot}41$ for boys and $\beta = -1{\cdot}68$, $P = 0{\cdot}17$ for girls). Both studies used 24 h recall to determine fibre intake[60].

Prospective cohort studies

Dietary fibre intake and body weight/composition

In a 5-year follow-up cohort study, associations between carbohydrate intake and BMI, percentage body fat and waist circumference among children (12 years) living in Sydney (*n* 513) were studied[66]. After multivariable adjustment, a mean increase of 7·1 g fibre intake/d in girls and 11·8 g/d in boys over the 5 years follow-up was associated with a decrease of BMI ($\beta = -0{\cdot}44$ (se 0·19), $P = 0{\cdot}02$) in girls and a decrease of waist circumference (mean −1·45 cm, $P = 0{\cdot}002$) in boys. This gender-specific association could have been due to different levels of physical activity or the lack of adjustment for pubertal stages. Although fibre intakes ranging from 15 to 40 g/d were wide enough to detect any effects, the body composition analysis could have affected the outcomes as bio-impedance analysis may underestimate when used in overweight children[77].

A German cohort of 215 adolescents was studied to determine associations between carbohydrate intakes and BMI and percentage body fat[64]. In a mixed gender with multivariable adjustment analysis, including puberty timing and concurrent changes, no associations between BMI nor percentage body fat and dietary fibre were reported. These findings are contrary to those of Gopinath *et al.*[66]. Baseline fibre intake (28·6 g/d) was also high in the German cohort, but it was obtained from weighed 3-d dietary records. Moreover, according to the baseline cross-sectional analysis, higher fibre intakes were associated with higher levels of BMI and percentage body fat, which demonstrated 'reversal causation' between fibre intake and adiposity (i.e. those who were already overweight would have been on a fibre-rich diet to lose weight). In a very large cohort (*n* 16 671) of US pre-adolescents and adolescents, dietary intakes were studied to determine associations with BMI at two time points within 1 year. Energy-adjusted fibre intake was not predictive of BMI change over one year. The lack of effect could be due to the short follow-up and residual confounders (e.g. physical activity levels)[63]. In contrast, a significant reverse association between energy-adjusted fibre intake at 16–19 years and concurrent change in waist circumference by age 36 years was reported in a Dutch cohort[69]. In a very small study (*n* 85), overweight US Latino children with a family history of type 2 diabetes were followed up for 2 years, an inverse association between energy-adjusted total and soluble fibre intakes and visceral adiposity was observed[65]. It is possible that the protective effects of dietary fibre may be exaggerated in this homogeneous at-risk cohort.

The fibre intake range in the cohort studies was generally wide which allows observing differences across the intake spectrum. Also, fibre intakes were higher than those reported in the general child and adolescent population, enabling detection of some effects. However, inconsistency still arose among these studies. This could be, to some extent, explained by the differences in baseline fibre intakes, fibre intake ranges, dietary measurement models used, adiposity measurements applied and other residual confounders. It is well acknowledged that accurate dietary assessment is notoriously difficult. In the case of children and adolescents, it may be more complicated by factors such as misunderstandings of children's portion size and daily variability[78]. The adjustments for co-variables were also different among studies. In addition, since dietary fibre is a component of overall diet and associated with other bioactive ingredients, e.g. in fruit and vegetables and whole grain the results could be a reflection of a 'healthy eating pattern' rather than the fibre *per se*.

Dietary fibre intake and blood pressure

The cohort from Sydney, Australia also looked at the association between carbohydrate intake and blood pressure[73]. A significant association between high total dietary fibre intake (7·1 g/d) and low blood pressure (i.e. systolic blood pressure, diastolic blood pressure and arterial blood pressure) was found only among girls (systolic BP $\beta = -0{\cdot}96$ (se 0·40; $P = 0{\cdot}02$); diastolic BP $\beta = -0{\cdot}62$ (se 0·25; $P = 0{\cdot}01$); arterial BP $\beta = -0{\cdot}75$ (se 0·24; $P = 0{\cdot}002$)). This gender-specific effect may be explained by different hormonal changes during adolescence[79]. In a cohort from Amsterdam, the Netherlands, 370 children were followed up from age 13 years until age 36 years, and a significant reverse association was found between dietary fibre intake at 16–19 years and arterial blood pressure at age 36 years after adjustment for sex, height and time of food measurement[68]. However, when more lifestyle co-variables (e.g. physical activity and alcohol consumption) were taken into account, the significant association was lost. Thus dietary fibre may be a surrogate marker of healthy lifestyle and may not exert the protective effects on blood pressure in isolation. In the same Amsterdam cohort, no significant association between blood pressure at age 36 years and fibre intake at 13–19 years was found before or after adjustment[69]. However, with a small sample size it may not be possible to maintain power while adjusting for several confounding factors.

The Sydney and Amsterdam cohorts exhibited relatively high total fibre intakes at baseline, 28 and 24 g/d, prospectively, both measured by FFQ which has a propensity for recall bias and misclassification[80], attenuating the effect size of dietary fibre. Moreover, according to the baseline characteristics such as BMI, family history of hypertension, the Amsterdam cohort was relatively healthier than the Sydney cohort. Therefore, the genetic differences in these populations might have attenuated these associations.

Dietary fibre intake and puberty timing

In a very small Dutch cohort of sixty-three pre-menarcheal girls (9·6 years), de Ridder *et al.* studied the association between diet and sexual maturation[72]. After a simple regression model adjusted for energy intake, height and timing of dietary measurement, fibre was found to be the most important dietary factor contributing to breast development at age 11·5 years and menarche at 14·3 years (for both $\beta = -2·6$, $P <$ 0·05). Koo *et al.* followed up a Canadian cohort of 637 pre-menarcheal girls, studying the association between dietary fibre intake and menarche. It was found that later menarche was associated with not only higher fibre intake, but also higher intake of its components cellulose and lignin (P for trend = 0·0269, 0·0090 and 0·0269, respectively)[67]. The association between isoflavone and dietary fibre intake in childhood to the timing of puberty was also studied in a German cohort[81]. Multiple puberty markers such as age at take-off, age at peak height velocity, age at voice break for boys and age at menarche for girls were examined. However, no association was found between dietary fibre intake and puberty timing after adjusting for co-variables, including isoflavone intake. Instead, a significant association was found between higher intake of isoflavone and later puberty timing.

Both Canadian and German cohorts reported a wide range of dietary fibre intake (5–40 g/d). Cheng *et al.* speculated that the significant association between dietary fibre intake with puberty timing observed in the Canadian and Dutch cohorts[67,72] may be masked by the lack of assessment of dietary phyto-oestrogen[81].

Dietary fibre intake and insulin resistance

In a US cohort of 774 girls (16–17 years), diet was evaluated for risk associations with development of insulin resistance[75]. Only the higher soluble dietary fibre component was significantly associated with lower fasting blood insulin concentration ($\beta = -0·93$, $P < 0·05$) and lower insulin resistance as measured by Homeostasis model assessment-IR ($\beta = -5·20$, $P < 0·05$). Neither soluble nor insoluble dietary fibre showed any association with fasting blood glucose concentrations. Although detailed nutrition status was profiled in this cohort, the adjustment did not include any other dietary factors, which may not disentangle the role fibre plays from that of any other co-existing nutrients. In addition, the dietary measurement used was 3-d food diaries, which may fail to reflect habitual eating patterns. The original cohort recruited was 2379 girls, but at follow-up only 774 girls provided valid data. The attrition rate was high, which may result in 'selection bias' and exaggerate the effect size.

In a much smaller Danish cohort (*n* 233), the association between fibre intake and insulin resistance among children (8–10 years) was prospectively investigated[60]. After 6 years follow-up, although Danish children generally had a fibre-rich diet, no significant association was detected between fibre intake and Homeostasis model assessment Z-score. However, the dietary intake was measured by a single 24 h dietary recall.

Conclusion

Dietary fibre, a heterogeneous group of non-digestible carbohydrates with different properties and actions, has been a challenging and controversial topic since the concept was firstly introduced. The association of dietary fibre with health outcomes such as CVD, and cancer is reasonably well-documented among adults. However, recommendations for children and adolescents remain extrapolation from adult data which are not appropriate. Children are not little adults and at younger ages fibre may have different actions in the gut and on health, in young children the gut and its bacteria are still developing[27]. This approach may result in recommended intakes for children which are difficult to achieve in younger ages.

However, there is still very limited evidence for the health effects of fibre in children, as found in our systematic review, on which to base more appropriate recommendations. Although some of these studies suggested that high-fibre intake might be associated with lower risk of obesity, constipation, metabolic syndrome, insulin resistance and blood pressure, there is an urgent need for more high-quality studies, both observational and intervention, in children.

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Conflict of Interest

C. A. E. is on working groups for ILSI Europe and has been involved in commercially funded research.

Authorship

C. A. E. and C. X. performed the data collection for the review and drafted major sections of manuscript C. A. E. supervised the process and drafted the manuscript. A. L. G. helped draft the manuscript and commented on final version.

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